(12) UK Patent Application (19) GB (11) 2 119 862 A

(21) Application No 8300212
(22) Date of filing 6 Jan 1983
(30) Priority data
(31) 375773
(32) 6 May 1982
(33) United States of America (US)
(43) Application published 23 Nov 1983
(51) INT CL[3] F04D 29/56 27/02
(52) Domestic classification F1V 104 602 616 630 640 702 DCC U1S 1987 F1V
(56) Documents cited
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(58) Field of search F1V

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(54) Variable stator vane (VSV) closed loop control system of a compressor

(57) The control system 28 includes biasing means 34 for effecting and maintaining an additional magnitude of positioning of the vanes 18, for example, about 2° to about 4° of additional closure, from a position as determined by demand indication A, such as VSV position from a VSV schedule (Figure 2) included in VSV control means 30.

The control system further includes feedback means 36 supplying a signal E representing the actual position of the vanes, a comparator 38 for supplying an error signal F in response to the feedback and demand signals and any bias signal and a servomotor means 40 for positioning the vanes in response to the error signal. In one embodiment, the biasing means are effective only after an aircraft takeoff mode of operation and while an engine operating parameter, for example, corrected engine speed, is within a predetermined range.

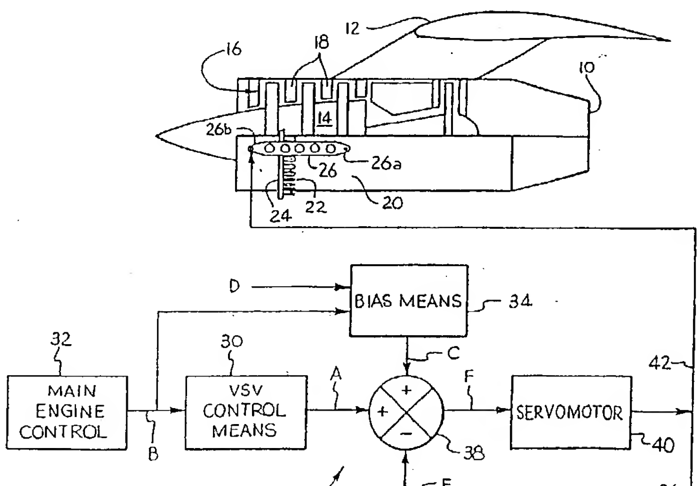

Fig 1

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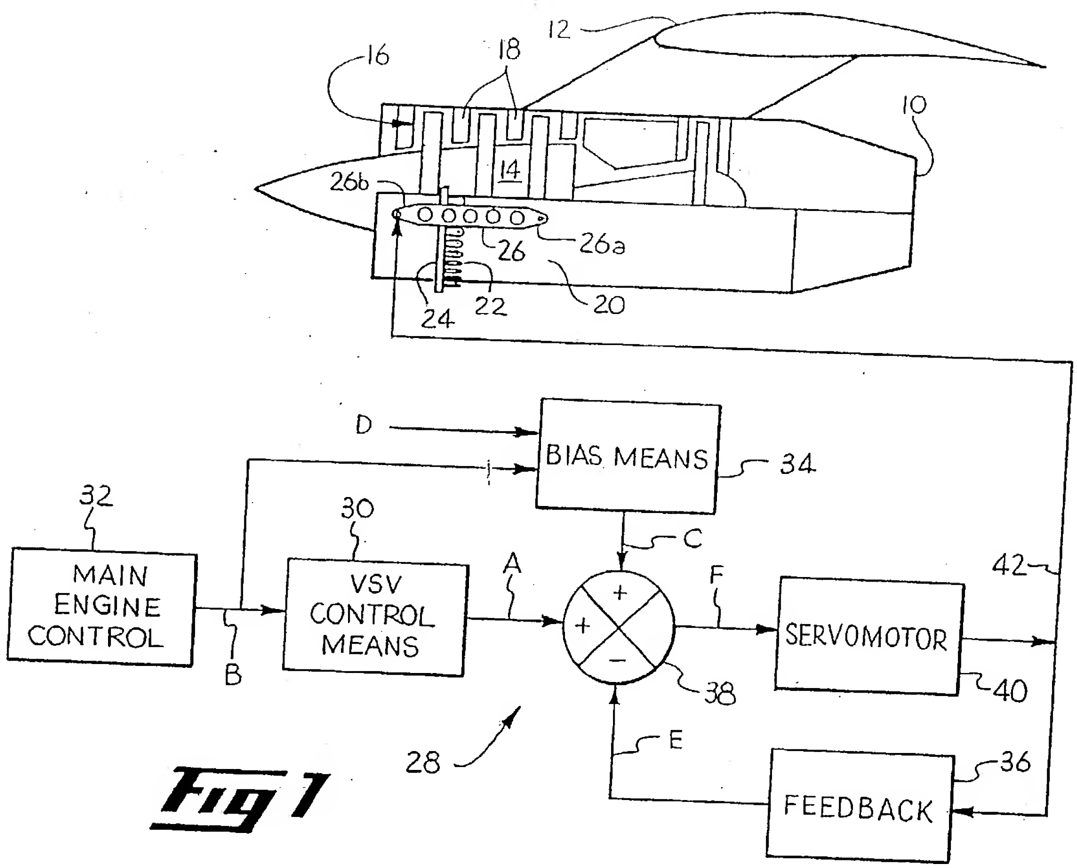


Fig 1

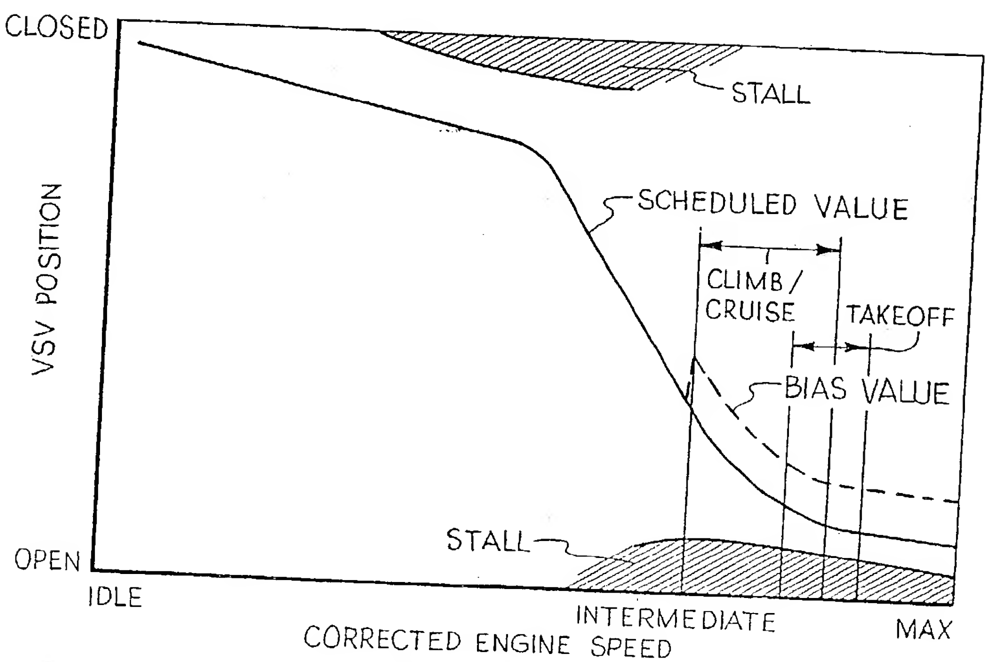
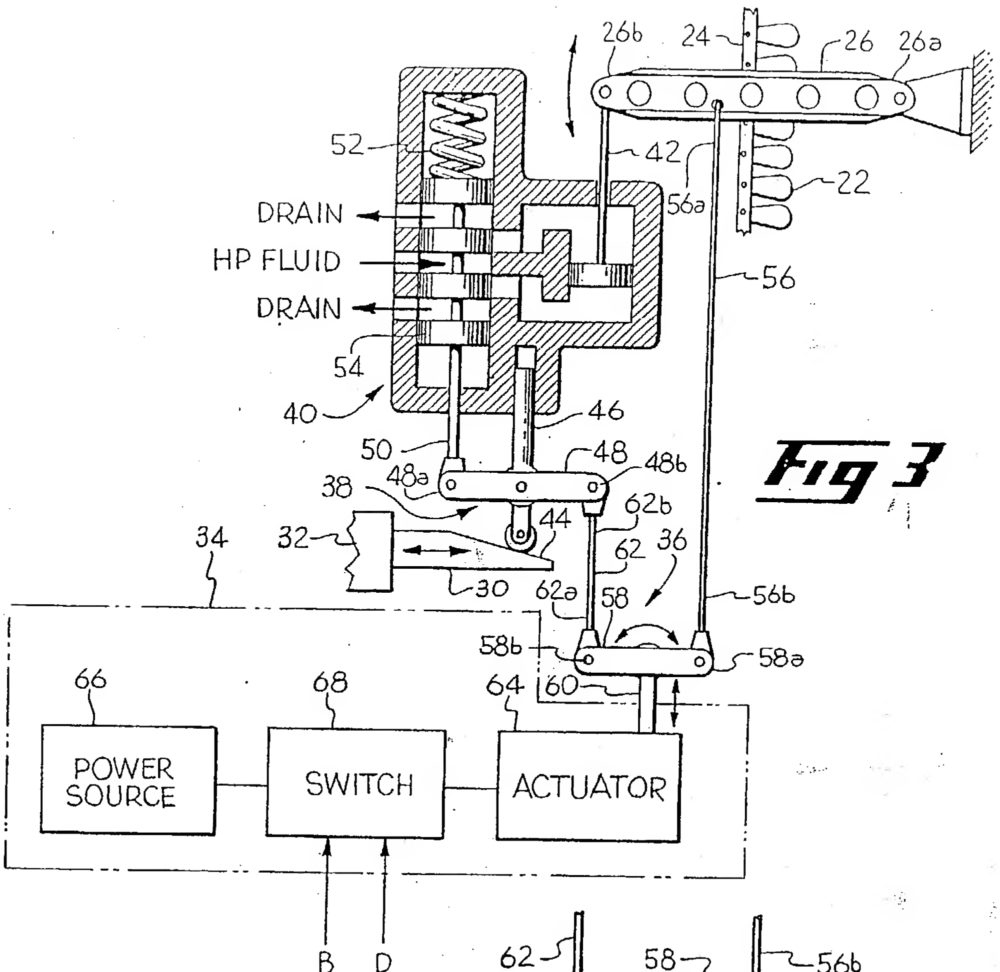


Fig 2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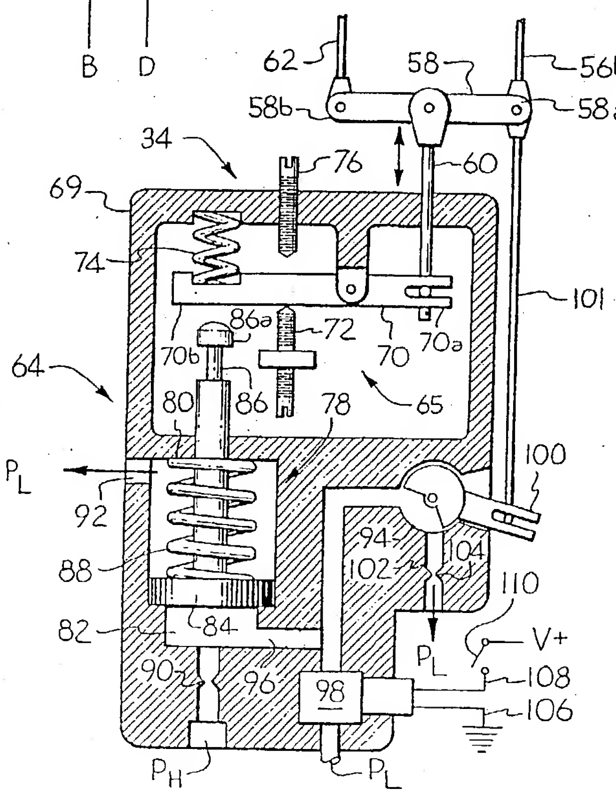
48a
38
62b
44
34
32
36
62
30
62a
58
56b
58b
58a
66
68
64
60
POWER SOURCE
SWITCH
ACTUATOR
B
D

Fig 3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58
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86a
72
70b
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86
78
65
100
P_L
92
94
102
104
88
110
84
V+
82
P_L
90
96
98
108
106
P_H
P_L

Fig 4

SPECIFICATION

Variable stator vane control system

Background of the invention

This invention relates generally to a control system for a gas turbine aircraft engine and more specifically to a control system for positioning the variable angle stator vanes of a compressor section thereof.

Aircraft powered by gas turbine engines are designed to operate during many modes of operation such as takeoff, climb, cruise, and descent. Each of these modes of operation requires a different thrust output of the gas turbine engine and results in various engine operating conditions. Accordingly, the gas turbine engine is designed for providing the appropriate thrust required for each of the aircraft modes of operation in addition to providing efficient engine performance therefor.

For appropriately controlling the operation of the gas turbine engine an engine control system is typically provided. The engine control system can include one or more predetermined schedules which take into account and balance many competing engine operating conditions for controlling engine performance in view of the anticipated modes of operation of the aircraft being powered by such an engine.

For example, a common goal in the design of a high performance gas turbine aircraft engine is to provide for increased performance of an axial flow compressor therein. One method of achieving this end is to provide the compressor with variable angle stator vanes, or simply variable stator vanes (VSVs). During engine operation, the engine control system controls the angular orientation, or pitch, of the VSVs in accordance with a predetermined, or fixed VSV position schedule and in response to an aircraft thrust selector lever.

The VSV position schedule provides the engine control system with a signal representing a desired VSV position as a function of thrust demand as represented by an engine operating parameter, such as corrected engine speed. For each value of corrected engine speed, the VSV position schedule provides a corresponding VSV position signal to the control system for positioning the VSVs.

It is generally desirable to control the pitch of the VSVs during periods of engine acceleration and increased engine thrust output to reduce any possibility of compressor stall. The normal manner of increasing engine thrust output is to increase the amount of fuel delivered to a combustion system of the gas turbine engine. The high fuel flow required therefor results in an increase in combustion burner pressure. This, in turn, decreases the airflow at the rear of the compressor and can result in compressor stall whereby airflow over the VSVs becomes turbulent resulting in reduced airflow, a reduction in compression ratio and a loss in performance. Accordingly, the VSV position schedule is predetermined for increasing compressor performance and reducing the likelihood of compressor stall.

The engine control systems found in the art typically function in response to the aircraft thrust selector lever position and the engine operating conditions in accordance with the predetermined schedules. Inasmuch as predetermined schedules are used, these control systems do not directly respond to the aircraft modes of operation and, accordingly they are thereby inherently limited in their ability to optimize engine performance.

For example, the VSV position schedule is derived by taking into account anticipated magnitudes of engine operation parameters such as, for example, fan and core engine speed, turbine inlet and exhaust gas temperature, compressor stall and thrust for effecting the required thrust output from the engine while optimizing the performance thereof.

The VSV position schedule is typically based on empirical data obtained from testing many engines under a full range of engine operating conditions through the various anticipated aircraft modes of operation from takeoff through landing. The finally determined VSV position schedule is chosen to provide for increased compressor performance and is proportional typically to corrected engine speed. However, inasmuch as the various anticipated aircraft modes of operation require different performance of the compressor and inasmuch as the aircraft modes of operation have overlapping regions with respect to corrected engine speed, the VSV position schedule generally represents a compromise schedule. The compromise schedule represents an average schedule for providing increased compressor performance throughout all combinations of aircraft modes of operation and corrected engine speeds.

For example, aircraft takeoff generally requires the greatest performance of the compressor and engine and, accordingly, the VSV position schedule is chosen to reduce the likelihood of compressor stall during takeoff.

However, it has been observed that compressor stall is most likely to occur, if at all, during the aircraft climb mode and between approximately 5,000 and 15,000 feet of altitude above a takeoff, ground surface. Inasmuch as the VSV schedule is fixed, it would be desirable to have independent means for reducing the liklihood of stall during the aircraft climb mode by introducing biasing to the VSV portion schedule. Such means should be more directly related to the aircraft modes of operation, such as for example, aircraft altitude. However, it is also preferred that the introduction of biasing occur in at least the aircraft climb mode and not occur during the takeoff mode during which the introduction of any biasing could result in decreased

Summary of the invention

Accordingly, it is one object of the present invention to provide a new and improved variable angle stator vane control system for a gas turbine aircraft engine.

Another object of the present invention is to provide a new and improved method for controlling a gas turbine aircraft engine.

Another object of the present invention is to provide a control system including biasing means for introducing biasing to a predetermined VSV schedule for reducing the likelihood of compressor stall.

Another object of the present invention is to provide a control system in which biasing is introducible in response to aircraft modes of operation.

Another object of the present invention is to provide a control system in which biasing is introducible selectively and independently of any preexisting control system schedules.

Another object of the present invention is to provide a control system in which the variable angle stator vanes are biasable in a more closed position for increasing engine performance.

Another object of the present invention is to provide a control system wherein any failure in the biasing means does not affect any preexisting control system schedules.

Briefly stated, the invention comprises a method and apparatus including a closed-loop control system for positioning variable angle stator vanes in a gas turbine engine effective for powering an aircraft. The control system includes biasing means for effecting and maintaining an additional magnitude of positioning of the vanes from a position as determined by a schedule. In one embodiment, the biasing means are effective only after an aircraft takeoff mode of operation and while an engine operating parameter is within a predetermined range.

Description of the drawing

The invention together with further objects and advantages thereof, is more particularly described in the following detailed description taken in conjunction with the accompanying drawing, in which:

Figure 1 is a view partly in section and partly in schematic illustrating a control system for positioning the variable angle stator vanes of an aircraft mounted gas turbine engine in accordance with the present invention.

Figure 2 is a graphical illustration of a variable angle stator vane position schedule for use in the control system of Figure 1.

Figure 3 is a schematic and sectional diagram illustrating one embodiment of the control system of Figure 1 in the form of a substantially mechanical closed-loop control system.

Figure 4 is a sectional view illustrating one embodiment of means for introducing biasing into the control system of Figure 3.

Detailed description

Shown in Figure 1 is an exemplary gas turbine engine 10 suitably mounted to a wing 12 of an aircraft. The engine 10 includes a compressor 14 at a forward end thereof which has a plurality of stages including a plurality of variable angle stator vane rows 16.

Each of the vane rows 16 includes a plurality of radially extending and circumferentially spaced VSVs 18. Each VSV 18 is suitably mounted in the compressor 14 and includes a radially outermost portion which extends through a stator casing 20 and has a positioning lever 22 attached thereto. The positioning lever 22 is pivotably connected at one end to an annular synchronizing and positioning member 24 which is suitably pivotably connected to an intermediate section of a VSV lever 26.

The VSV lever 26 further includes a proximal end 26a, pivotably connected to a fixed structure in the engine 10, and a distal end 26b, the movement of which is effective for rotating, in turn, positioning member 24, positioning levers 22, and the VSVs 18.

Also illustrated in Figure 1 is a closed-loop engine control system 28 for controlling and effecting the positioning of the VSVs 18 in accordance with one form of the present invention. The control system 28 includes a VSV control means 30 which is effective for suppyling a demand indication A. The indication A is proportional to the magnitude of an engine operating parameter, or indication B obtained from a main engine control 32 not part of the present invention.

The main engine control 32 controls many functions of the gas turbine engine 10 and it is sufficient for the purpose of the present invention that when a thrust selector lever in the aircraft is positioned, the main engine control 32 provides a magnitude of the desired engine operating parameter B in accordance with a desired engine performance required for any aircraft mode of operation. An example of a typical engine control system including a VSV control means is disclosed in U. S. Patent 2,931,168-Alexander et al, incorporated herein by reference.

The VSV control means 30 includes a VSV position schedule such as is shown in Figure 2. For a given engine indication B such as, for example, corrected engine core speed, a value of a demand indication A, such as VSV position, is generated. The corrected engine core speed is defined as $N_2/\sqrt{CIT/519°R}$; where N_2 is physical engine core speed and CIT is compressor inlet temp which equals ambient temperature plus fan

longitudinal axis. The VSV position can range in value, for example, from approximately −5° at engine maximum speed to approximately 40° at engine idle speed. The −5° pitch, or relatively open position, hereinafter referred to as open, indicates that the VSVs 18 are oriented for allowing increased flow of air thereover. The 40° pitch, or relatively closed position, hereinafter referred to as closed, indicates that the VSVs 18 are positioned for allowing a decreased flow of air thereover. It will be observed in Figure 2 that the scheduled value of the VSV position is proportional to the corrected engine speed and varies from a closed position at idle to an open position at maximum engine speed.

Two regions of possible compressor stall have been determined and are indicated in Figure 2; a first stall region occuring at an intermediate engine speed with the VSVs 18 near the closed position; and a second stall region occuring at high engine speeds when the VSVs 18 are positioned near the open position. The region between the curve of VSV position scheduled value and the stall regions is referred to as a stall protection margin.

The VSV scheduled value is predetermined on the basis of considerations such as the engine operating parameters as above described, as well as others. The schedule of VSV position can also take into account those factors for obtaining good engine specific fuel consumption and providing a stator vane stall protection margin for reducing the possibility of undesirable compressor stall.

According to the present invention, it has been determined that a significant increase in stall protection margin and improved specific fuel consumption of the engine can be realized by introducing a VSV position bias value in addition to the scheduled value of VSV position as shown in Figure 2. More specifically, by biasing the VSVs 18 in a more closed position, for example during aircraft climb, improved compressor and engine performance is realizable.

In one form of the invention, the bias value (shown as a dashed line in Figure 2) is introducible when the corrected engine speed is within a predetermined range between an intermediate value and a maximum value corresponding with the second stall region. However, inasmuch as the corrected engine speed typically includes overlapping regions of climb, cruise and takeoff as shown in Figure 2, an additional consideration is required which will prevent the introduction of any biasing during aircraft takeoff, while allowing biasing over the entire predetermined engine speed range only after the aircraft has passed through the takeoff mode of operation. This is desirable inasmuch as the aircraft takeoff mode requires takeoff performance characteristics of the engine which characteristics have been included in the original VSV schedule and which could adversely be affected by the introduction of VSV position biasing during the takeoff mode.

However, once the aircraft has passed through the takeoff mode and when the engine speed is within the predetermined range, the introduction of VSV position biasing results in improved engine performance. Accordingly, biasing means 34, as shown in Figure 1, are provided for supplying a bias indication C having a value corresponding to an additional closure of the VSVs of approximately 2° to approximately 4° as shown in Figure 2.

In one embodiment, the bias indication C is effective for additionally closing the VSVs 18 only after the aircraft takeoff mode and while the corrected engine speed is within the predetermined range. In this connection, one input to the biasing means 34 is the engine indication B and another input thereto is an indication D responsive to the aircraft modes of operation.

The control system 28 further includes feedback means 36 for supplying a feedback indication E representing actual position of the VSVs 18. Comparing means 38 are also provided for supplying an error indication F in response to the demand indication A, bias indication C and feedback indication E. For example, the indication F is equal to the sum of the indications A and C minus the indication E. Servomotor means 40, having a movable output member 42 suitably connected to the distal end 26b of the VSV lever 26 is provided for positioning the VSVs 18 in response to the error indication F.

The details of operation of closed-loop, negative feedback control systems are well known to those skilled in the art and a further description thereof is therefore deemed not necessary for the understanding of the present invention. In the present invention, biasing means 34 are provided in combination with the closed-loop control system 28 for obtaining an improved engine control system for positioning the VSVs 18. The closed-loop control system 28 as illustrated in Figure 1 can comprise, for example, an electrical, hydraulic, electromechanical or a substantially mechanical system. Furthermore, the indications A through F can be signals which may, for example, be electrical, hydraulic, mechanical or any combinations thereof. Illustrated in Figure 3 is a substantially mechanical, closed-loop control system according to one form of the present invention.

Referring to Figure 3, the main engine control 32 (partially shown) is suitably connected to the VSV control means 30. The VSV control means 30 comprises a longitudinally translatable cam having a cam profile 44 which is effective for providing the demand indication A in accordance with the VSV scheduled value as shown in Figure 2, and in response to the engine indication B. More specifically, the demand indication A is determined by the position of a cam follower 46 against the cam profile 44.

The cam follower 46 is part of the comparing means 38 and can comprise an elongate member which has a first end for following the cam profile 44 and a second end which which is slidably mounted, for example in

40. The control member 50 is oriented preferably perpendicularly to the cross member 48.

The error indication F is determined by the position of the first end 48a of the cross member 48 and is generated by the combined rotation of the cross member 48 and translation of the following 46 attached thereto. A second end of the control member 50 is supported in the servomotor 40 against a return spring 52. The spring 52 is effective for supplying a force against the control member 50 to allow and to aid the control member 50 to be positioned between its limits of travel.

One example of a suitable servomotor 40 is shown in Figure 3 in which the second end of the control member 50 includes suitable valve portions 54, four for example, which control the passage of a suitably supplied high pressure fluid into the servomotor 40. The high pressure fluid is effective for moving the output member 42 of the servomotor 40 in either of two opposite directions and supplying sufficient force to actuate the VSV lever 26 for positioning the VSVs 18 in response to the VSV control means 30.

Other embodiments of suitable servomotors 40 known in the art which include an input control member 50, an output member 42 and a return spring 52 can be used.

Suitably connected adjacent to the distal end 26b of the VSV lever 26 and extending in a direction substantially parallel to the output member 42 is a first end 56a of a first feedback linkage 56. A second, opposite end 56b of the first feedback linkage 56 is suitably connected to a first end 58a of an elongate feedback lever 58 pivotably mounted at an intermediate section thereof to a translatable fulcrum member 60.

Suitably connected to a second, opposite end 58b of the feedback lever 58 is a first end 62a of a second feedback linkage 62. A second, opposite end 62b of the second feedback linkage 62 is suitably attached to a second, opposite end 48b of the cross member 48. The feedback linkages 56 and 62 can comprise any suitable rod, cable and housing, or other structures which are capable of transmitting tensile and compression forces therethrough for rotating the feedback lever 58 and the cross member 48.

The first feedback linkage 56, feedback lever 58, fulcrum member 60 and second feedback linkage 62 comprise the feedback means 36 as shown in Figure 1. The rotation of the VSV lever 26 causes, in turn, the translation of the first feedback linkage 56, the rotation of the feedback lever 58 about the fulcrum 60 and the translation of the second end 62b of the second feedback linkage 62. The translation of the second feedback linkage 62 represents the feedback indication E as shown in Figure 1.

In operation, the main engine control 32 causes the cam profile 44 to predeterminedly translate longitudinally. The follower 46, in turn, translates transversely in response to the location of the cam profile 44. Inasmuch as the second end 48b of the cross member 48 is effectively restrained by the feedback means 36, due to the relatively large forces required to rotate the VSV lever 26, the translation of the follower member 46 causes the cross member 48 attached thereto to rotate about the second end 48b thereof. The cross member 48 thus rotates in a first direction and causes the control member 50 of the servomotor 40 to translate and thus opens appropriate passages therein for supplying high pressure fluid to the servomotor 40 for moving the output member 42.

The movement of the output member 42 causes the VSV lever 26 to rotate about its proximal end 26a and in turn causes the rotation of the synchronizing member 24, levers 22 and accordingly the VSVs 18. The rotation of the VSV lever 26 also causes the rotation of the cross member 48 of the comparing means 38 in a second direction, opposite to the first direction, thus completing the closed-loop feedback path of the control system 28.

The above description represents the basic closed-loop control system for actuating the VSVs 18. The introduction of a bias indication C (Figure 1) in accordance with the present invention can be accomplished by various means. A preferred means for introducing a bias indication C into the control system 28 comprises longitudinally translating the fulcrum member 60 attached to the feedback lever 58.

More specifically, as shown by the double headed arrow in Figure 3, the longitudinal translation of the fulcrum 60 in a direction generally parallel to the first and second feedback linkages 56 and 62, respectively, causes an additional rotation of the cross member 48 of the comparing means 38 and thus a bias indication C. The particular arrangement and structure of elements in the feedback means 36 is selected such that less force is required to rotate cross member 48 than to rotate VSV lever 26. Accordingly, when the fulcrum member 60 is caused to translate longitudinally, the first end 58a of the feedback lever 58 attached to the first feedback linkage 56 remains substantially at one position in space. The second end 58b of the feedback lever 58 will rotate about the first end 58a thereof in response to the translation of fulcrum 60 and cause the second feedback linkage 62 to rotate the cross member 48.

To control the position of the fulcrum member 60, the biasing means 34 can comprise an actuator 64 suitably connected to the fulcrum 60. The actuator 64, when supplied with suitable power from a power source 66 upon the activation of a switch 68 suitably connected thereto, can move the fulcrum member 60 to a predetermined position.

The biasing means 34 can comprise many embodiments. Illustrated in Figure 4 is a preferred embodiment for use in the control system illustrated in Figure 3. More specifically, the fulcrum member 60 attached to the feedback lever 58, is mounted to an output means 65 of the actuator 64 such that the fulcrum member 60 can be translated in a longitudinal direction.

The output means 65 includes an elongate reset lever 70 pivotably mounted at an intermediate section to a housing 69 of the biasing means 34. The reset lever 70 is oriented preferably perpendicularly to the fulcrum

compression spring 74, against an adjustable first stop 72 suitably attached to the housing 69.

The spring 74 is disposed between the housing 69 and a second, opposite side of the second end 70b of the reset lever 70. Facing the second side of the reset lever 70 and disposed oppositely to the first stop 72 is a second adjustable stop 76 predeterminedly spaced therefrom.

It will be apparent that, in operation, when the second end 70b of the reset lever 70 is displaced from the first stop 72 further against the compression spring 74 and towards the second stop 76, the reset lever 70 is rotated about the intermediate section thereof and thus causes the first end 70a of the reset lever 70 to translate the fulcrum 60 longitudinally downwardly as can be appreciated in Figure 4.

The first and second stops 72 and 76 are adjustable such that when the reset lever 70 is in a first, initial position urged against the first stop 72 (as shown) no biasing is introduced into the control system. When the reset lever is in a second position urged against the second stop 76, a predetermined, adjustable maximum amount of biasing is introduced into the control system.

Referring to Figure 4, the actuator 64 can comprise a fluidic timer 78 including a cylindrical housing 80 having a timing chamber 82 at one end thereof bounded on one side by a piston or diaphragm 84. The piston 84 includes an integral output member or rod 86 extending outwardly from and through the housing 80. The output rod 86 includes a distal end 86a spaced from and oriented perpendicularly to the first side of the second end 70b of the reset lever 70 and disposed oppositely to the compression spring 74. A return spring 88 is disposed coaxially about the output rod 86 and against a bottom surface of the housing 80 and an inner surface of the piston 84. The return spring 88 is effective for returning the rod 86 and the piston 84 to a first, initial position as shown. It is to be appreciated that both the reset lever 70 and the rod 86 comprise one embodiment of the output means 65 of the actuator 64 for translating the fulcrum 60. Other suitable embodiments can also be used.

The fluidic timer 78 also includes a vent 92 connected to a low pressure return P_L for venting any fluid in the housing 80 and on the backside of the piston 84.

High pressure fluid P_H is suitably provided to the timing chamber 82 through a first orifice 90. The fluid P_H is supplied from the power source 66 (as shown in Figure 3) which, can comprise, for example, high pressure compressor interstage air or pressurized fuel.

The timing chamber 82 is connected to the switch 68 (Figure 3) which, in a first state, is effective for allowing the fluid P_H to flow into the fluidic timer 78 for extending the rod 86 thereof for moving the fulcrum 60 to the predetermined position. The switch 68, in a second state, is effective for venting the fluid P_H in the fluidic timer 78 and allowing the return spring 88 to return the rod 86 to the initial position for removing the bias indication C.

In a preferred embodiment the switch 68 comprises a first valve 94 and a second valve 98. The first valve 94 is connected to the timing chamber 82 by a fluidic conduit 96. The first valve 94 is connected also to P_L by a fluidic conduit 102 having a second orifice 104 disposed therein. Connected to an intermediate section of the fluidic duct 96 is the second valve 98. The second valve 98 can comprise an electrically operated solenoid valve. In the second state, the first valve 94 and the second valve 98 are in a normally open position for venting any fluid flow in the fluidic conduit 96 to P_L.

The first valve 94 includes an actuating lever 100 suitably connected to the first end 58a of the feedback lever 58 by a rod 101. Thus, the first valve 94 is coupled by the rod 101 and is responsive to the corrected engine speed as indicated by the position of the feedback lever 58. The lever 100 has a predetermined travel such that it closes the first valve 94 after a predetermined rotation of the feedback lever 58 and thus during the predetermined range of corrected engine speed. This is so inasmuch as corrected engine speed is proportional to VSV position, as can be appreciated from Figure 2. Accordingly, the first valve 94 is simply an on-off valve or switch which is effective for allowing the biasing means 34 to actuate only during the predetermined range of corrected engine speed.

The second, solenoid valve 98 is connected by a first electrical lead 106 to a suitable electrical ground and by a second electrical lead 108 to an electrical switch 110 which is connected to a voltage source. The closing of the switch 110 provides the indication D to the biasing means 34 as shown in Figures 1 and 3. When closed, the electrical switch 110 causes the normally open second valve 98 to close, i.e. to assume the first state, thereby preventing any fluid in the fluidic conduit 96 from venting through the second valve 98.

The first valve 94 and the second valve 98 comprise an embodiment of the switch 68 which requires both valves to be actuated to respective first states before the biasing means 34 is actuated. Of course, the valves could be used singly, however, if desired.

Furthermore, it is to be appreciated that the biasing means 34 is actuatable independently and selectively of the basic control system 28 and the VSV position schedule, as shown in Figure 2. This is due to the use of a switch 68 which can be actuated, for example, directly by the pilot of the aircraft, by an altmeter, or in response to engine speed or combinations thereof.

During engine operation, high pressure fluid P_H is provided through the first orifice 90 to the timing chamber 82. Inasmuch as the first valve 94 and the second valve 98 are in a normally open position, the high pressure fluid P_H in the timing chamber 82 is vented through both halves and accordingly the output rod 86 of the fluidic timer 78 remains in the initial position. Inasmuch as the timer 78 is normally in an unactivated

When the engine 10 is accelerated during aircraft takeoff, the VSVs 18 are caused to to be rotated by the main engine control 32 from a closed position to an open position. Accordingly, the first feedback linkage 56 is translated vertically by the VSV lever 26 as shown in Figures 3 and 4 and, in turn, causes the actuating lever 100 to close the first valve 94 thereby preventing venting therethrough.

However, although the first valve 94 is closed during aircraft takeoff, the second valve 98 remains open and thus vents any high pressure fluid P_H found in the conduit 96, thereby preventing actuation of the fluidic timer 78 of the biasing means 34.

Once the aircraft is in the climb or cruise mode, the electric switch 110 can be closed, for example in response to raising of the landing gear and retraction of the wing slats of the aircraft or, if desired, manually by a pilot of the aircraft or in response to an altimeter. At this time, with both the first valve 94 and the second valve 98 closed, no venting of the high pressure fluid P_H can occur. Accordingly, high pressure fluid P_H can accumulate in the timing chamber 82 of the fluidic timer 78 and cause the piston 84 and the output rod 86 to translate and thus actuate reset lever 70 as above described.

The fluidic timer 78 is a device well known in the art and it can be suitably designed such that the output rod 86 travels from the initial, unextended position to a fully extended position in the course of seconds to hours. For example, the first orifice 90 and the elements of the fluidic timer 78 an be selected such that, in combination with a predetermined high pressure fluid P_H, full travel of the output rod 86 occurs in approximately 5 to 6 minutes after the first valve 94 and second valve 98 are closed to coincide with an expected aircraft altitude of approximately 8500 feet. In this manner, no biasing is introduced during aircraft takeoff.

Alternatively, the timer 78 can be designed for a full travel in approximately 12 seconds, for example, in the event the biasing means 34 is to be actuated almost immediately in response to a demand and after the closing of the valves 94 and 98.

In a preferred embodiment, a bias indication C representing approximately 4° of additional VSV closure is provided by the biasing means 34 until such time as the electrical switch 110 is opened, thus opening the second valve 98 and venting the high pressure fluid P_H from the timing chamber 82. This allows the return spring 88 to return the rod 86 to an initial position, and thereby remove any VSV bias indication C from the control system 28.

The fluidic timer 78 may be deactivated, alternatively, by the opening of the first valve 94. During descent of the aircraft, the engine is returned to substantially an idle condition in which the VSVs 18 are returned to a substantially closed position by the main engine control 32. In turn, the first feedback linkage 56 is caused to return to a substantially initial position thus moving the lever 100 and opening the first valve 94 to allow the venting of any high pressure fluid P_H in the fluid conduit 96. The second orifice 104 is predeterminedly sized greater than the first orifice 90 to control the rate at which the high pressure fluid P_H is vented and, thereby, controls the rate at which the fluidic timer 78 is deactivated and any biasing is removed from the control system.

The first valve 94, the second valve 98 and the fluidic timer 78 comprise one means by which biasing can be introducible selectively and independently of any preexisting control system schedules and more directly in response to aircraft modes of operation. More specifically, the first valve 94 assures that biasing can be introducible only during a predetermined range of corrected engine speed as represented by the position of the feedback lever 58. The second valve 98 is controlled by the switch 110 which is only actuatable after aircraft takeoff and which can be used to disable the actuator 64, if desired.

While there has been described herein what is considered to be a preferred embodiment of the invention, other modifications will occur to those skilled in the art from the teachings herein.

For example, the fulcrum 60 can be translated by various alternative structures. An actuator 64 comprising an electric motor controllable in response to an electrical switch 68 can be used. A bias indication C can be introduced into the control system 28 by varying the lengths of the first and second feedback linkages 56 and 62 of the feedback means 36.

CLAIMS

1. For an engine control system for positioning a plurality of variable angle stator vanes of a compressor in a gas turbine engine between a relatively open and a relatively closed position in accordance with a VSV schedule and in response to a variable engine operating parameter, said engine being effective for powering an aircraft in takeoff, climb and cruise modes of operation, said engine control system comprising:

biasing means for effecting and maintaining an additional magnitude of positioning of said vanes over a position as determined by said VSV schedule and being effective only after said takeoff mode and while the magnitude of said engine operating parameter is within a predetermined range.

2. The biasing means according to claim 1 wherein said biasing means are effective for introducing a predetermined additional closure of said vanes during said climb mode.

3. The biasing means according to claim 1 wherein said biasing means are effective for introducing a predetermined additional closure of said vanes after said aircraft attains a predetermined altitude and during

operation.

5. The biasing means according to claim 1 wherein said biasing means are effective for supplying a bias indication proportional to said additional magnitude of positioning of said vanes, and said engine control system comprises:

control means for supplying a demand indication representing a desired vane position in accordance with said VSV schedule;

feedback means for supplying a feedback indication representing actual position of said vanes;

comparing means for supplying an error indication in response to said feedback and demand indications and any bias indication; and

servomotor means having a movable output member effective for positioning said vanes in response to said error indication.

6. The biasing means according to claim 5 wherein said engine control system and said biasing means comprise substantially mechanical elements.

7. The biasing means according to claim 5 wherein said feedback means comprises:

a feedback lever having first and second oppositely extending ends and pivotably mounted at an intermediate section thereof to a fulcrum movably mounted to said gas turbine engine;

a first feedback linkage joining said output member of said servomotor and said first end of said feedback lever and being effective for rotating said feedback lever in accordance with any rotation of said vanes as indicated by the position of said output member of said servomotor;

a second feedback linkage joining said second end of said feedback lever to said comparing means of said engine control system for providing said feedback indication thereto; and

wherein said biasing means comprises an actuator having output means effective for moving said fulcrum of said feedback means to a predetermined position and thereby rotating said feedback lever for generating said bias indication.

8. The biasing means according to claim 7 wherein said actuator comprises a fluidic timer being connectable to a source of high pressure fluid in said gas turbine engine, and wherein said output means comprises an output member of said fluidic timer and wherein said actuator further comprises a switch which, in a first state, is effective for allowing said high pressure fluid to flow into said fluidic timer for extending said output member thereof for moving said fulcrum to said predetermined position, and which, in a second state, is effective for venting high pressure fluid in said fluidic timer and allowing a return means to position said output member thereof to an initial position for removing said bias indication.

9. The biasing means according to claim 8 wherein said switch comprises a first valve responsive to said engine operating parameter and a second valve responsive to said aircraft modes of operation, and wherein said output member of said fluidic timer is movable from said initial position to said extended position when both said first and second valves are in respective first states.

10. An engine control system for a gas turbine engine including a compressor having a plurality of variable angle stator vanes, said engine being effective for powering an aircraft in takeoff, climb and cruise modes of operation comprising:

means for positioning said plurality of vanes between a relatively open and a relatively closed position in accordance with a VSV schedule and in response to a variable engine-operating parameter; and

biasing means for effecting an additional magnitude of positioning of said vanes over a position as determined by said VSV schedule only after said takeoff mode and while the magnitude of said engine-operating parameter is within a predetermined range.

11. A method for controlling a gas turbine engine including a compressor having a plurality of variable angle stator vanes, said engine being effective for powering an aircraft in takeoff, climb and cruise modes of operation comprising:

positioning said plurality of vanes between a relatively open and a relatively closed position in accordance with a VSV schedule and in response to a variable engine-operating parameter; and

effecting an additional magnitude of positioning of said vanes over a position as determined by said VSV schedule only after said takeoff mode and while the magnitude of said engine-operating parameter is within a predetermined range.

12. Biasing means substantially as hereinbefore described with reference to and as illustrated in the drawings.

13. A method of controlling a gas turbine substantially as hereinbefore described with reference to the drawings.

Printed for Her Majesty's Stationery Office, by Croydon Printing Company Limited, Croydon, Surrey, 1983.
Published by The Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.